# HISTORICAL AND RECENT DISTRIBUTION OF HUMPBACK WHALES IN SHARK BAY, WESTERN AUSTRALIA

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Aerial surveys from 1986 to 1999 indicate a substantial increase in humpback whale (*Megaptera novaeangliae*) numbers in Shark Bay, Western Australia, and provide geographical distribution patterns. A comparison with post World War II catch data (1951-1961) reveals a similar distribution. Bathymetry, water temperature and salinity may influence whale distribution in Shark Bay. Areas of apparent congregation and the correlation with differing boundaries of the Marine Park and World Heritage listed areas are discussed. ❒ *Humpback whale, Megaptera novaeangliae, Shark Bay, distribution, environment, salinity, sea surface temperature, aerial survey.*

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Humpback whales, *Megaptera novaeangliae*, migrate annually from cold Antarctic Area IV (70°E-130°E) feeding grounds, north along the coastline of Western Australia between May and August to breed in warm tropical waters, and then south between August and December returning to Antarctica. Historically, large numbers of humpback whales were hunted off Western Australia and in the Antarctic Area IV feeding grounds during the mid to late 1930's (Bannister, 1995). Ten years later whaling recommenced at Point Cloates, 250km north of Shark Bay in 1949 and at Carnarvon in 1950 (Fig. 1), with the two operations running concurrently until 1955 when all operations were combined at Carnarvon. They continued there until 1963, resulting in a possible 95% reduction in numbers (from an estimated 12-17,000 individuals to ~ 800) and an uneconomic basis for further whaling (Chittleborough, 1965).

Recent aerial surveys of Shark Bay and vessel-orientated photographic identification studies in the Dampier Archipelago of northwestern Australia have provided independent population estimates for this Group IV stock of more than 4,000 animals (Bannister, 1991,1994; Jenner & Jenner, 1994) with an annual rate of increase of about 10%. A specific aerial survey was undertaken from June to August 1999 off Shark Bay to estimate this population (Bannister & Burton, 2000; Bannister & Hedley, 2000). A calculated figure of 4,000 animals from this survey is thought to under-estimate the true population. A revised methodology has produced an estimate of between 6,000 and 10,000 humpback whales (Bannister, 2001).

Western Australia has an extensive 12,000km coastline between 12°S and 34°S, 3,000km north of Antarctica. Humpback whale populations move adjacent to the west and northwest sections of coastline, which have several large bays and embayments that are visited during the migration (Jenner et al., 2001). One of the largest of these is Shark Bay, a relatively shallow basin (10-20m) spanning ~8,000sq km of water and separated from the Indian Ocean by three north trending barrier islands, Dirk Hartog, Dorre and Bernier Is (Fig. 1). Shark bay was given World Heritage status in 1991 and has a number of marine protected areas (Fisheries Department of WA, 1994) and a large marine park within its boundary (CALM, 1996) (Fig. 1).

Within Shark Bay, the Peron Peninsula divides the southern half into two semi-enclosed NW-SE elongate gulfs (Fig. 1). These have variable water temperature and salinity regimes (Logan & Cebulski, 1970; Logan & Brown, 1986; Burling, 1998). Water salinity and density increase markedly to the south from the northern oceanic water (Fig. 2A). Low runoff, restricted water circulation and high evaporation promoted by high ambient air temperatures and strong winds are responsible for hypersaline waters at the head of the gulfs, and subsequent maintenance of a number of salinoclines (Bruce, 1997). These two inner gulfs are also characterised by seasonally, highly variable water temperature regimes, with summer having much warmer water and winter much cooler water than the adjacent ocean (Fig. 2B).

The Leeuwin Current, a seasonally varying flow of warm, tropical, low-salinity water 200m

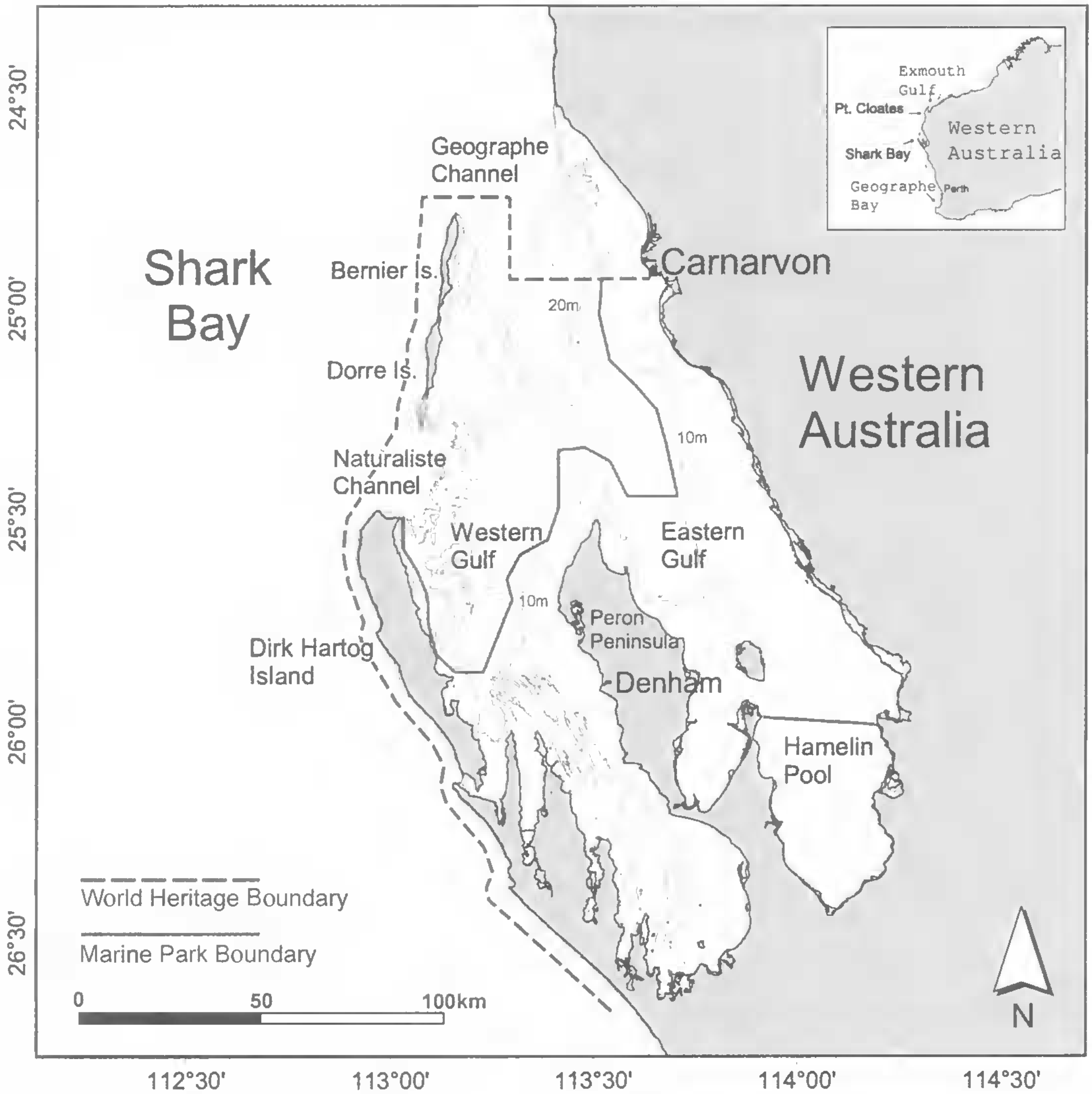


FIG. 1. Map of Shark Bay, Western Australia, showing study area and bathymetry contours.

deep and 100km wide, moves down the Western Australian coast past Shark Bay and into the Great Australian Bight at a speed of between 0.5-1.5m/s. It is strongest between April and October (Pearce & Cresswell, 1985) having an influence on most fisheries and habitats on the west coast (Lenanton et al., 1991; Caputi et al., 1996).

This paper reports on the distribution of humpback whales inside Shark Bay in historical and recent terms. Historically, changes in monthly distribution of catches inside Shark Bay between 1951 and 1961 are considered. In recent terms the recovery of this population of humpback whales, as demonstrated by aerial surveys conducted since 1976, is considered. Distribution patterns of whales inside Shark Bay are related to environmental parameters, unique to this area.

## METHODS

*Historical Whaling Catch Data*. Whale chasers operating from Carnarvon were required to keep daily logs. The whaling company also kept detailed records of each whale killed and the amount of oil produced each week. Experienced scientific and technical personnel working at the

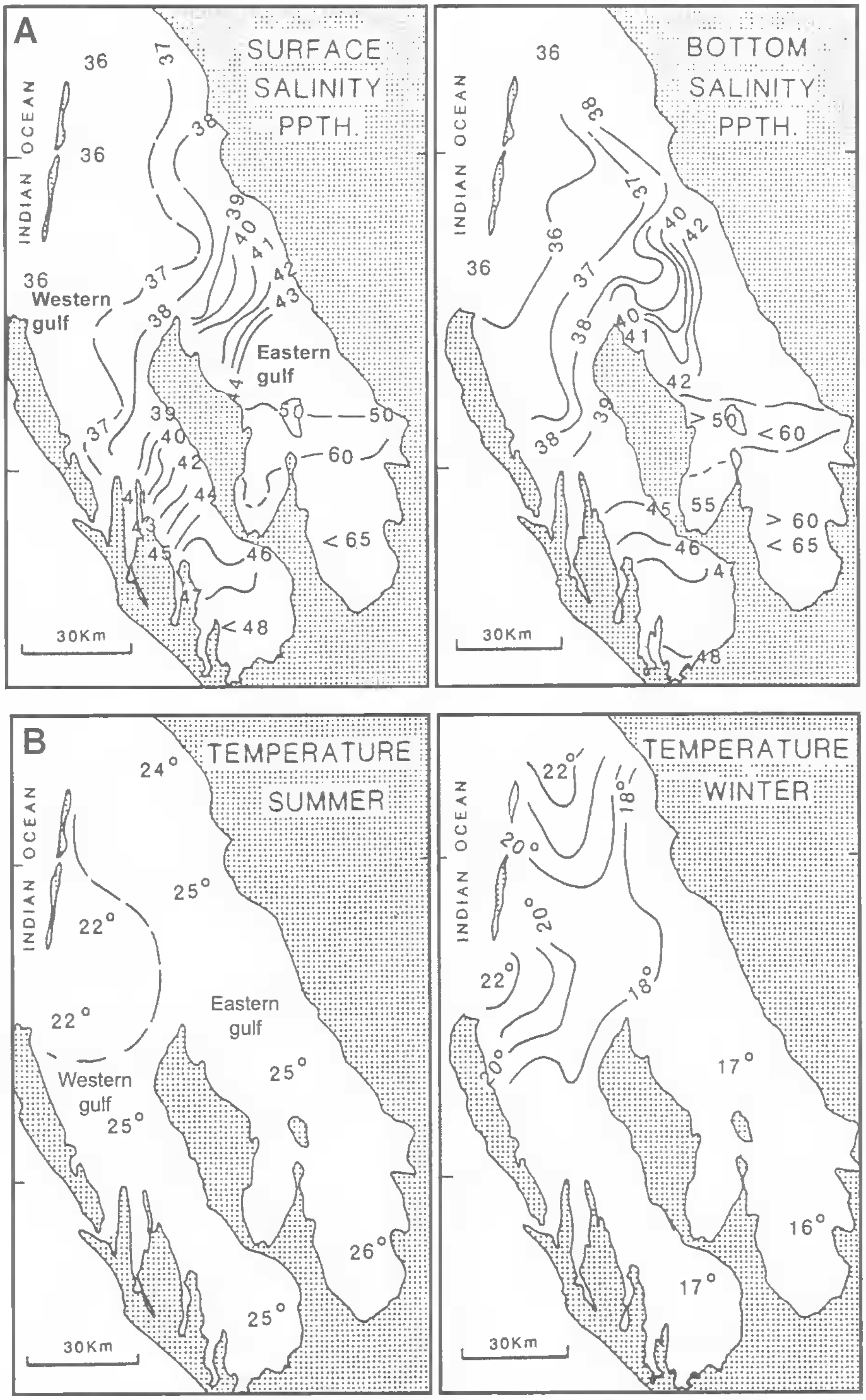


FIG. 2. A, typical patterns of salinity distribution during summer, with strong gradients from ocean passages to the southern extremities of gulfs. B, typical patterns of water temperature distribution for summer and winter (after Logan & Brown, 1986).

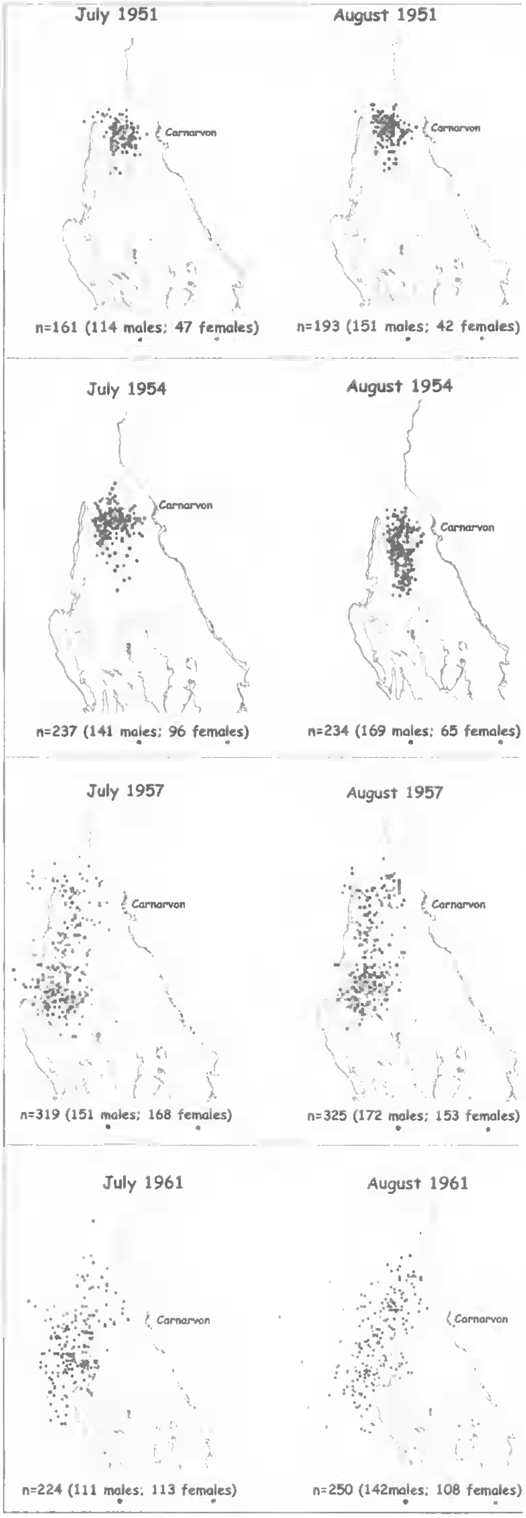


FIG. 3. Plotted positions of humpback whale catches for particular months.

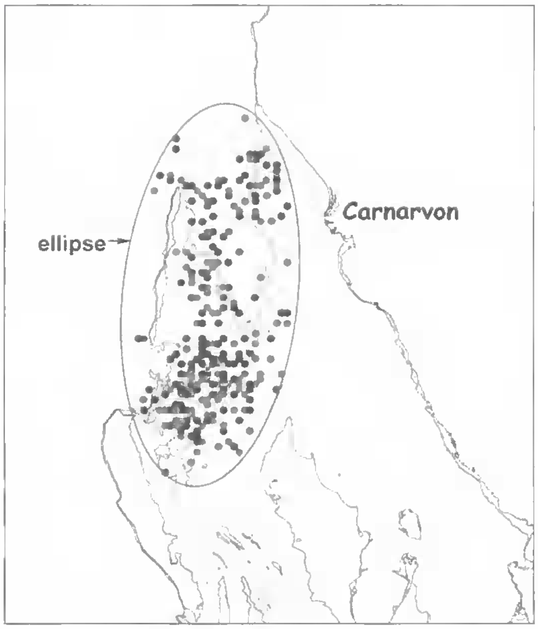


FIG. 4. Delineated area in which humpback whales were caught in Shark Bay (shown for August 1957).

whaling station each winter, sampled as many carcasses as possible (Chittleborough, 1965).

Daily records from four evenly spaced years between 1949 and 1963 were entered into a database. The positions (latitude and longitude) of animals killed during June, July, August and September of 1951, 1954, 1957 and 1961 were plotted onto outlines of Shark Bay using 'Arcview GIS' software. Of these months, only July and August are represented in all four years (Fig. 3), and are used to investigate the changes in monthly distribution during this period of intensive whaling effort.

An index of whale (catch) density was calculated by approximating the area covered by whale chasers for each year and dividing it by the number of whales killed in that area. An ellipse was drawn over each monthly plot of whales caught so that all catch positions were inside the perimeter, and the area calculated with 'NIH Image' software, using a standard calibrated distanee (Fig. 4).

*Recent Aerial Surveys*. To estimate relative abundance of humpback whales migrating along Western Australia's coast, a series of aerial surveys have been conducted approximately every 3 years since 1976 up to 1994, following a consistent pre-determined fight path outside Shark Bay (Bannister, 1994) (Fig. 5). These surveys were conducted with an experienced pilot/observer and one observer in a high wing Cessna 337 aircraft. For the purpose of this paper, individual sighting locations of humpback whales observed from the three transit legs inside Shark Bay during the aerial surveys conducted in 1986, 1988, 1991 and 1994 are used to estimate the latitude and longitude for each whale. Cumulative numbers of humpback whales observed on the transit legs over a similar 10-day period in July in each of these years are presented in Fig. 6.

In 1999, a comprehensive aerial survey was undertaken on the northern migration outside Shark Bay (Bannister & Burton, 2000; Bannister & Hadley, 2000). Observations made on the three transit legs inside Shark Bay were comparable to the earlier flights and are used in this study (Fig. 6). In addition to this survey, which extended from late June to mid August 1999, six flights were conducted inside Shark Bay between July 5 and August 16, using a grid that effectively covered the areas where whales had been sighted during previous surveys, and where humpback whales were taken during whaling (Fig. 7). This survey was conducted to collect whale distribution data in Shark Bay rather than abundance.

A twin engine Partenavia high-wing aircraft with two dedicated observers was used at 1500ft and 120 knots ground speed. The aircraft was fitted with bubble windows on either side. Numbers of whales and pods, directions of movement, behaviour and accurate GPS positions were logged. Angles of declination were measured using a clinometer. The perpendicular distance of each sighting from the aircraft was calculated using the angle of declination to each sighting and the height of 457m above sea level. Distances from the port and starboard sides of the aircraft were then converted into proportions of latitudes and longitude for plotting in Arcview. Transects were between 7 and 8 nautical miles (nm) apart to minimise duplicate sightings.

## STUDY AREA

Studies of the geology and oceanography of Shark Bay (Logan & Cebulski, 1970; Logan & Brown, 1986) indicate a semi-arid climate with a diverse range of habitats including arid surrounding lands, extensive seagrass banks of *Amphibolis antarctica*, *Posidonia australis* and *Halodule uninervis* (Walker, 1989), coral reefs, shallow sand areas and deep water muds. The water body is reasonably well mixed vertically but varies spatially. The marine environment is characterised by a diverse range of hydrographic features including seasonally variable water temperatures (15-30°C) and broad salinity gradients (35-65ppt) in the two gulfs within the bay (Fig. 2). The water mass in Shark Bay is divided into three main categories (Logan & Cebulski, 1970) based on characteristic salinity and density values: oceanic (35-40ppt), metahaline (40-56ppt) and hypersaline (56-70ppt) (Fig. 8). Boundaries of these water masses are located at salinoclines, where the salinity gradient is steep. The large Cape Peron salinocline delineates inner gulf waters from oceanic water (Fig. 8) remaining a permanent feature in summer, but less strongly developed in winter (Logan & Cebulski, 1970). Water temperatures and salinity values north and west of this feature approximate those of oceanic waters entering from the adjacent continental shelf through both Geographe and Naturaliste Channels (Logan & Cebulski, 1970; Logan & Brown, 1986; Burling, 1998).

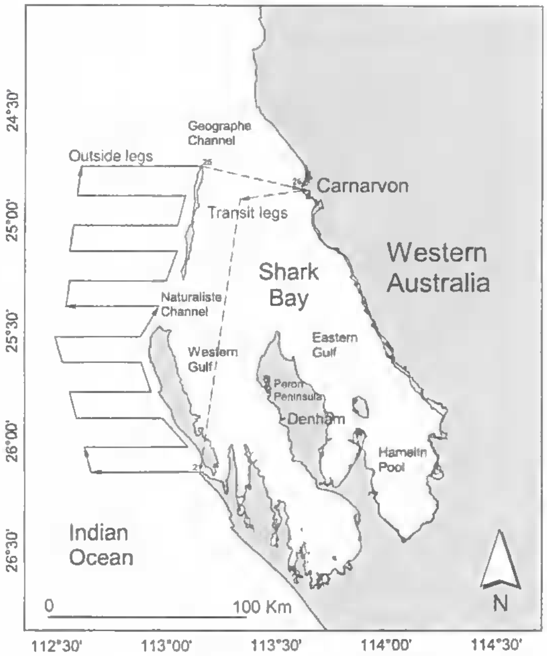


FIG. 5. Flight path for aerial surveys conducted outside Shark Bay during July between 1976 and 1999.

*Remotely Sensed Images*. To observe the variation in water temperatures in Shark Bay on a broad scale, remotely sensed images of sea surface temperature (SST) derived from the Advanced Very High Resolution Radiometer (AVHRR) instrument aboard the NOAH satellite were acquired from CSIRO marine laboratories in Western Australia, corresponding to the date

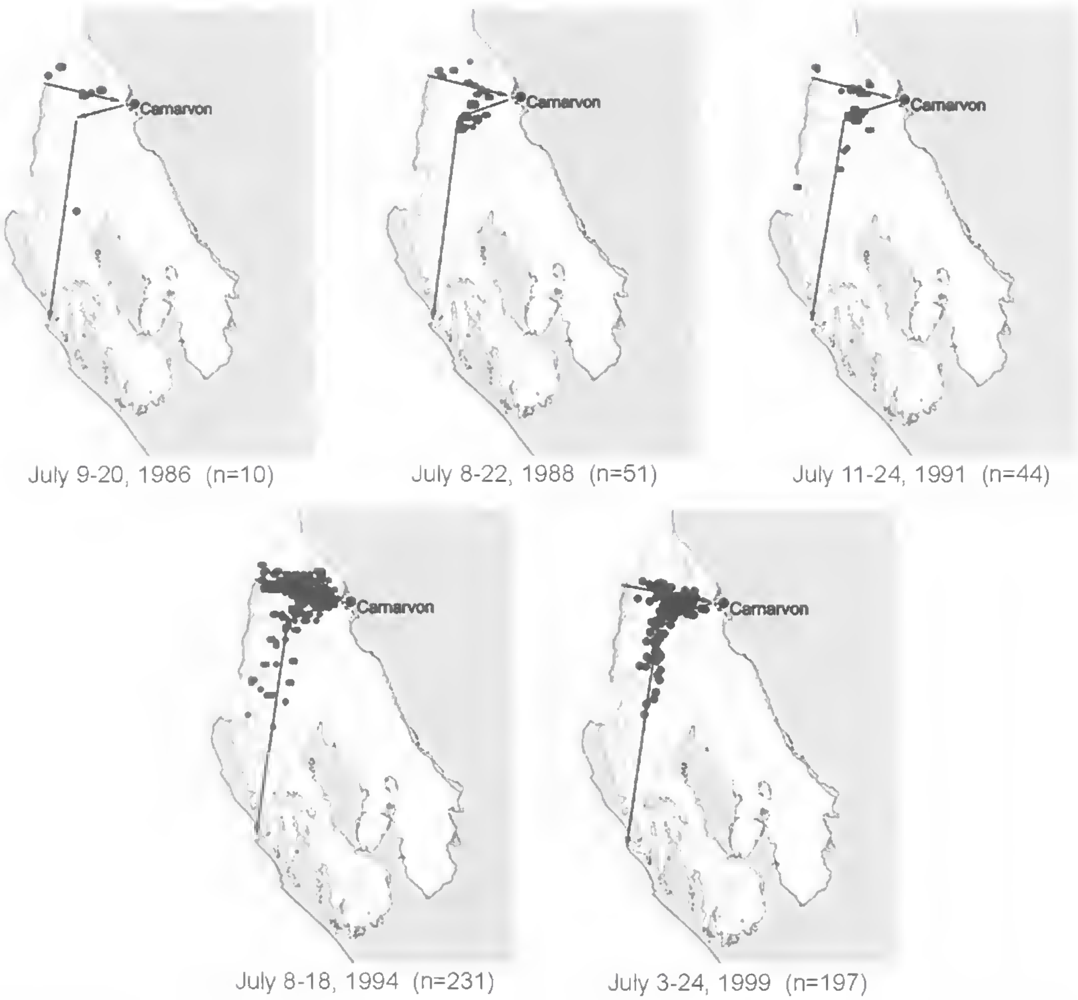


FIG. 6. Plotted positions of whales sighted on the 'inside legs' of flight path for aerial surveys conducted between 1986 and 1999.

closest to each flight of the survey. Observations of whale sightings made during the aerial survey in 1999 (flights 1,2,5 and 6) are overlaid onto these calibrated SST images and bathymetry, using 'Arcview GIS' software (Fig. 9).

## RESULTS

HISTORICAL. Plots of humpback whale catches in Shark Bay for four years between 1951 and 1961 show large differences in distribution and density of catches. Distributions of catches in July and August of 1951 and 1954 are similar (Fig. 3) with catches concentrated in the central northern part of the Bay, just west of Carnarvon. By 1957, the catch distribution was spread over a much larger area within Shark Bay, extending south into the western gulf. Most whales were caught outside Shark Bay in 1961, with fewer catches made inside Shark Bay (Fig. 3).

Density of whale catches decreased dramatically between 1954 and 1957, as the area searched by the chasers increased from approximately 4,000sq nm to over 6,000sq nm (Fig.10A). By 1961 the search area had increased to over 12,000sq nm. The crude index of catch density reflects this situation with a dramatic fall from 0.23 whales per square nm in 1951 to 0.05 in 1961 (Fig. 10B). Whales were killed predominantly in the northern central areas close to the whaling station up to 1954, extending to the lower areas of the Bay into the western gulf from 1957 (Fig. 3). No whales were taken from the eastern gulf during the four years of data sampled for this work.

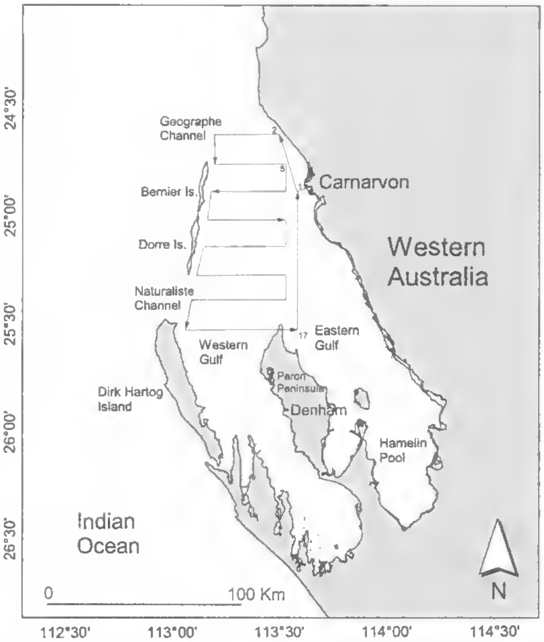


FIG. 7. Flight path for aerial surveys conducted inside Shark Bay during July and August of 1999.

RECENT: AERIAL SURVEYS. Plotted whale sighting data from the three transit legs of the aerial surveys in July 1994 and 1999 show higher numbers of humpback whales than in 1986, 1988 and 1991 (Fig. 6). For the combined 10-day survey periods of each year, these figures indicate a relative increase in the number of whales in the northern area close to Carnarvon. In 1994 and 1999 more whales were observed further south in central Shark Bay.

In 1999 the six surveys flown on the dedicated grid pattern inside Shark Bay (Fig. 7) indicate a much broader distribution (Fig. 9) than those sightings taken from the three transects of the bay on the standard grid pattern (Fig. 6), due mainly to the increased number or survey legs. The effective area surveyed per flight was approximately 1600sq nm with a total transect distance of 280nm. Details of each completed flight are shown in Table 1. The total number of whales sighted was 310 comprising 302 (97.4%) humpback whales (including 18 probable), 2 probable southern right whales and 6 unidentified whales. Average flight time was 2.5hrs (se = 0.088) and the mean number of humpback whales sighted per hour was 19.5 (se = 4.1). The total hours of flying were adjusted by –0.1hrs to remove the time taken to move to and from the first and last waypoint. The number of whales observed inside

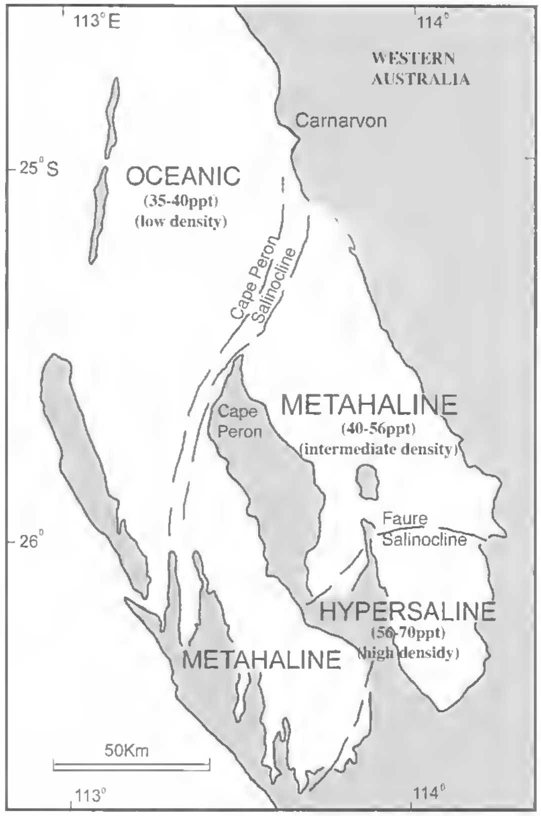


FIG. 8. Three bodies of water in Shark Bay (after Logan & Cebulski, 1970).

Shark Bay continued to increase into August as those observed outside the Bay began to decrease (Fig. 11A). The number of humpback whales sighted/adjusted hour steadily increased from 7.5 on July 5 to 37.2 on August 16 (Fig. 11B). Between 93 and 98% of sightings were within 4.5-7km from the trackline respectively (Fig.12).

In early July (flights 1 and 2, Fig. 9), humpback whales were found within Shark Bay, predominantly in the northern sector. By August (flights 5 and 6, Fig. 9), large numbers of humpback whales were more evenly distributed, in both deep and shallow areas, extending from west of Carnarvon, south to the northern opening of the western gulf. Most whales were observed in areas of water temperatures of 20°C or warmer and west of a line from Cape Peron to Carnarvon. Few sightings were made in the eastern part of the survey area.

## DISCUSSION

Extensive research undertaken on this Group IV population of humpback whales and on the

TABLE 1. Shark Bay humpback whale aerial survey June-August 1999. Summary of completed 'inside' flights.

| Flight date | HB | HB? | Total HB | Other whales | Flying hours | Adjusted hours(-0.1) | HB/Hour |
|---|---|---|---|---|---|---|---|
| 5-Jul-99 | 19 | 0 | 19 | 0 | 2.6 | 2.5 | 7.6 |
| 12-Jul-99 | 35 | 0 | 35 | 2 | 2.5 | 2.4 | 14.58 |
| 23-Jul-99 | 52 | 3 | 55 | 0 | 2.6 | 2.5 | 22.00 |
| 31-Jul-99 | 31 | 7 | 38 | 1 | 2.6 | 2.5 | 15.2 |
| 10-Aug-99 | 55 | 7 | 62 | 4 | 3.1 | 3 | 20.67 |
| 16-Aug-99 | 92 | 1 | 93 | 1 | 2.6 | 2.5 | 37.2 |
| Total | 284 | 18 | 302 | 8 | 16 | 15.4 | |

Group V population along the east coast of Australia during the 1950's, documented their decline during commercial whaling operations and added considerably to knowledge of their biology (Chittleborough, 1965). During 14 years of whaling on the West Australian coast, over 12,000 animals were killed. At Carnarvon, quotas were allocated each year and varied when the operations from Point Cloates were combined with those in Shark Bay and when catches began to decline in 1958.

In Western Australia during the early 1950's many humpback whales could be found inside Shark Bay. The catch distribution did not reflect the actual distribution of animals in the area, as whale chasers could locate whales close to their base at Carnarvon. As the population declined from the late 1950's the density of whales decreased and whalers had to increase their search effort to a much wider area and employ the use of spotter aircraft to maintain catches (Chittleborough, 1965). This is evident with the distribution of catches in 1957 (Fig. 3) which shows a much wider spread, predominantly south into the north of the western gulf. No humpback whales were caught in the eastern gulf of Shark Bay during these years. The eastern gulf was rarely searched as few whales were expected there, and no whales were observed in the western gulf during transit to Denham while undertaking a marking program (Chittleborough, pers. comm.). No literature is available describing the presence of whales in the eastern gulf. By 1961, chasers had to travel predominantly outside Shark Bay to find whales, as densities inside had dramatically decreased.

It could be inferred from the change in catch distributions from 1951 to 1961 that the density of whales in the early 1950's would have been high throughout the northern sector of Shark Bay, down to the western gulf, even though whales were only caught close to Carnarvon. Whalers did not have to search a large area. However, the distribution inside Shark Bay seemed confined to an area west of a line from Carnarvon to Peron Peninsula, and half way down the western gulf.

Aerial surveys from the late 1970's conducted outside Shark Bay during the northern migration in July show a major population increase since 1982 (Bannister, 1991, 1994). The most recent surveys (1994, 1999) strongly suggest that as the population has increased, so the proportion of whales found inside the bay (39.7% and 27.3% of total sightings respectively) is also increasing, although less so in 1999 (Fig. 11) (Bannister, 1994; Bannister & Burton, 2000). The increase in proportion observed inside the Bay (from 15.4% to 39.7%) in 1991 and 1994 respectively, seems abnormally high given the time difference of three years between these surveys. An explanation for the apparent inter-annual differences in whale numbers inside Shark Bay may be that the peak in migration could have been missed in 1991 and therefore fewer whales were present during the time of the survey. Variability in timing of the peak of the northern migration may be up to three weeks, possibly influenced by the availability of food in the Antarctic (Chittleborough, 1965).

Reasons why whales are observed inside Shark Bay are unclear. There are no data that define the residence times of animals which visit the bay, as only limited photo-id work has been carried out here (Table 2) with six pods observed over four days of effort during 1999. Of 15 humpback whales identified from 1985 to 1989 in Shark Bay by the author, one animal was photographed on 12 July 1989, then observed twice 10 weeks later off Perth, 800km south, in September (Burton, 1991). The factor of site selection or specificity by individuals or certain proportions of the population could play a role here: i.e. particular individuals may travel to particular areas of the Western Australian coast and remain there,

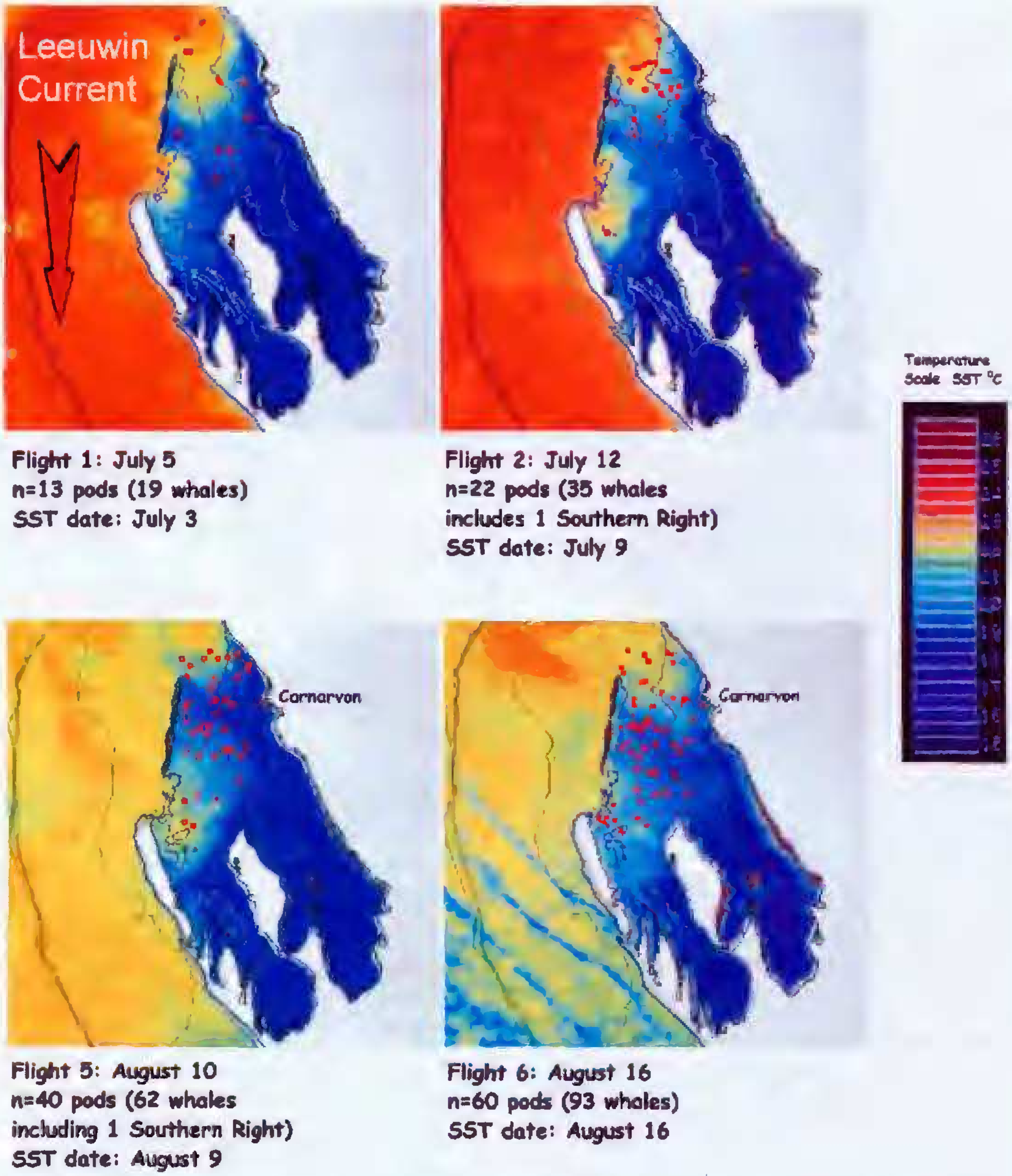


FIG. 9. Whale sightings overlaid onto SST images during 4 of the 6 flights conducted inside Shark Bay in 1999.

without traversing the whole coastline during the migration. It is quite likely that a proportion of this population may spend some time in Shark Bay, as individuals have been observed in waters off Perth from between four and seven days (Burton, 1991). Further matching of photographs from a recently developed computer assisted database may provide other resights along the Western Australian coast (Elford, pers. comm.) and assist with answering several of these questions.

During the northern migration, humpback whales enter Shark Bay through both major

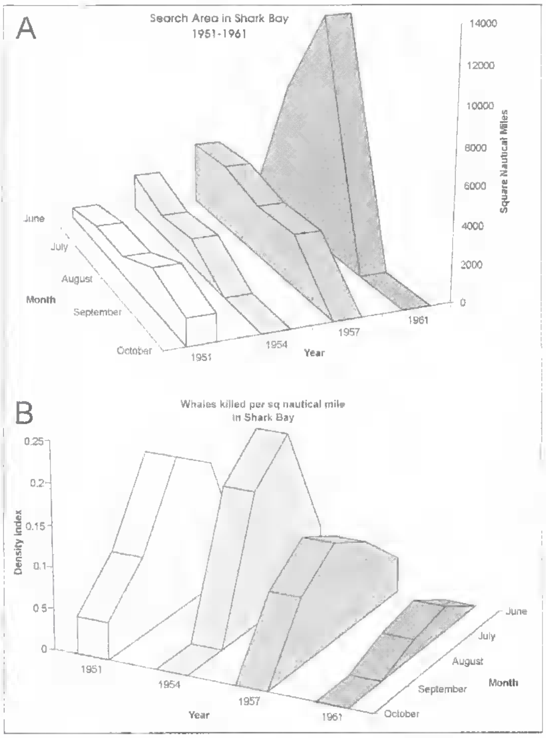


FIG. 10. Quantitative description of the search area (A) for each of the 4 years and a density index (B) of whales killed within those areas.

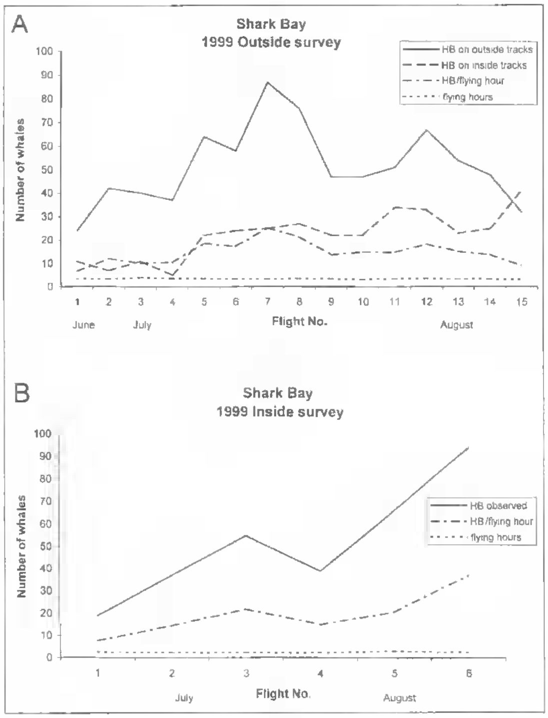


FIG. 11. Whales sighted during aerial surveys in 1999 outside (A) and inside Shark Bay (B).

entrances, Naturaliste and Geographe Channels (Fig. 1). Shark Bay may be an important resting area for the north-bound whales as they would be swimming against a strong south-flowing Leeuwin current (Pearce & Cresswell, 1985). Outside Shark Bay the majority of north-bound whales are within 10-15nm from the coast (Bannister & Burton, 2000). Only a small proportion were observed further offshore, possibly explained by the fact that the strongest flow of the Leeuwin Current is southward along the continental shelf during autumn to spring (Pearce & Cresswell, 1985), i.e. approximately 30-50nm outside Shark Bay. During the southern migration, whales would probably enter Shark Bay through Geographe Channel, as it is a natural opening to the migration corridor from the north.

A comparison of the directional movement of humpback whales observed during the outside legs and inside bay flights in 1999 indicates a lower proportion of animals moving north (9%) inside the bay compared to outside (44%), and a higher proportion moving in all other directions (Table 3). Although these data represent a 'snapshot' of behaviours in time during the northern migration, they do indicate that there is less northward movement by those animals inside Shark Bay, and that there is reason to believe that some animals are resting or milling there.

Satellite derived sea surface temperature (SST) images show the interaction of the Leeuwin Current with surrounding water masses (Prata el al., 1989) (Fig. 9). It appears that the direct influence of the Leeuwin Current is restricted to the northern regions of Shark Bay, with little effect on the eastern and western gulfs (Burling, 1998). The intrusions of oceanic water into the

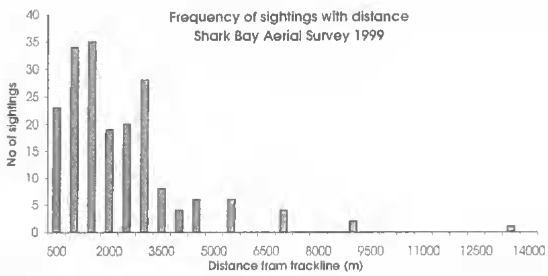


FIG. 12. Frequencies of whales sighted at various distances from the aircraft, 1999.

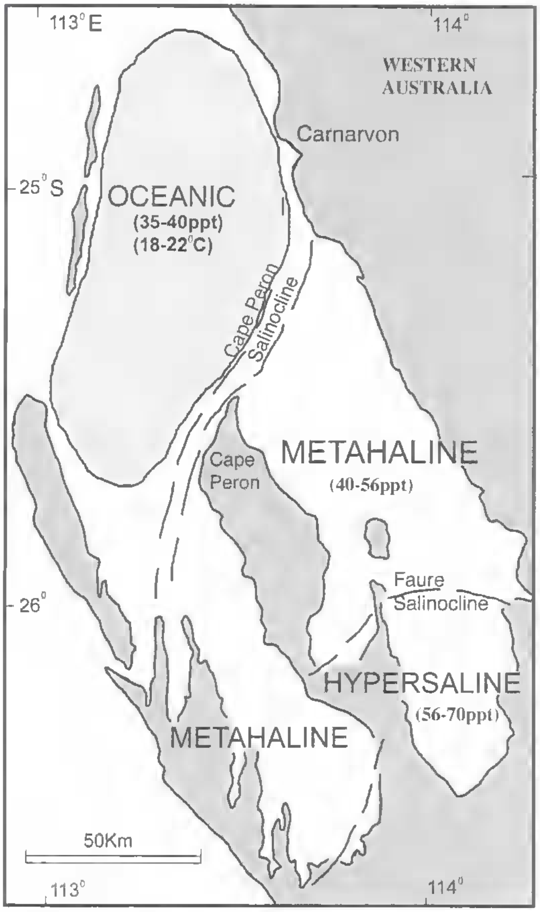


FIG. 13. Distribution of humpback whales in relation to the winter oceanic regime inside Shark Bay.

Bay as observed in the SST images (Fig. 9) appear to be tidally driven, and are augmented by persistent southerly winds. Large scale exchange of bay water with oceanic water seems to be restricted to winter months (Burling, 1998).

The number of humpback whales inside Shark Bay steadily increases from June to August as the peak of the northward migration passes in July, and southerly migrating animals begin appearing (Figs 3, 9). Densities increase within Shark Bay and distribution expands through the central and western parts with observations until early November, based on recent whale-watching data. No whales were caught in the eastern gulf area nor were any observed there during aerial surveys in 1999. Strip-transect aerial surveys conducted in Shark Bay in July 1989 and June 1994 for estimates of dugong (*Dugong dugon*) abundance also found relatively few humpback whales (Preen et al., 1997). During these surveys, the majority of humpback whales (13 of 14 in 1994 and all 6 in 1989) were found in the northern and western areas of the bay and it was thought that their distribution was restricted to the oceanic waters there. An aerial survey to estimate dugong abundance during July 1999 also found few humpback whales, with none sighted in the eastern gulf (Gales & McCauley, pers. comm.).

TABLE 2. Photo-id data collected inside Shark Bay, June and July 1999. ad = adult, sad = sub-adult, fl = fluke, ld = left dorsal, rd = right dorsal.

| Date | Pod details | Photo-id details | Individual id |
|---|---|---|---|
| 26/6/1999 | Pod 1 2ad 1sad | fl1 ld1, rd2 | 2 |
| 27/6/1999 | Pod 1+2 3ad 1sad | fFl1-3 | 3 |
| | Pod 3 1 Bryde's whale | rd | 1 |
| 11/7/1999 | Pod 1 2ad | ld1 | 1 |
| | Pod 2 2ad | fl1 | 1 |
| 20/7/1999 | Pod 1 cow/calf | rd cow, rd calf | 2 |

Distribution of whales inside Shark Bay may be related to unique environmental conditions such as water temperature, salinity and bathymetry. The inner, southern areas of Shark Bay are shallower, more saline and exhibit large seasonal variations in water temperature (Logan & Cebulski, 1970). The Cape Peron salinocline (Fig. 13) may present a natural barrier to the movement of whales down the eastern gulf, where salinity increases markedly and water temperatures are lower than the oceanic waters north of Cape Peron during winter.

There have been no recorded observations of humpback whales feeding in Shark Bay. No food remains were reported in stomachs of humpback

TABLE 3. Proportions of humpback whales moving in the compass rose directions, from the aerial surveys outside and inside Shark Bay 1999.

| Direction component | Outside flights (n whales =773) | Inside flights (n whales =302) |
|---|---|---|
| North | 43.9% | 8.94% |
| Northeast | 5.82 % | 6.62% |
| Northwest | 0.26 % | 7.95 % |
| South | 5.69 % | 8.29 % |
| Southeast | 0.39 % | 6.95 % |
| Southwest | 0.78 % | 2.65 % |
| East | 0.91 % | 2.32 % |
| West | 1.04 % | 3.64 % |
| Other | 41.27 % | 52.65 % |
| Total | 100% | 100% |

whales sampled at Carnarvon (Chittleborough, 1965). The zooplankton of the area was shown to be abundant in the central part of the bay, decreasing by four orders of magnitude to the southern hypersaline gulfs (Kimmerer et al., 1985). Other whale species have been recorded inside Shark Bay, the author observing a Bryde's whale feeding on small pelagic fish, 5 miles to the north of Cape Peron in 1998 and another Bryde's whale in the northern sector during vessel-based photo-identification trips in 1999 (Table 2).

North of Shark Bay along Ningaloo Reef, small amounts of zooplankton including *Euphasia hemigibba* and *Pseudeuphausia latifrons*, were found in the stomachs of 5 humpback whales examined during whaling from Point Cloates (Fig. 1), (Chittleborough, 1965). Recent work off Ningaloo Reef has discovered inter-annual summer variation in macrozooplankton, including *P. latifrons*, that relate to gross changes in oceanographic conditions (S. Wilson, pers. comm.). Wilson et al. (2001) describes the daytime swarming behaviour of *P. latifrons* off Ningaloo in relation to feeding by manta rays and whale sharks. A recent sighting of a blue whale feeding in waters off the Ningaloo continental shelf area was made during an aerial survey for humpback whales (C. Jenner, pers. comm.).

It is expected that the recovering Group IV population of humpback whales will increasingly use Shark Bay. Whales are observed in the northern and western areas of the bay where oceanic conditions predominate (Fig. 13). They seldom venture further south into the bay possibly because oceanic water is restricted from moving into these gulfs by the complex hydrographic regime of salinoclines associated with hypersaline water. It is noteworthy that the state Marine Park boundary almost totally excludes the area in which the majority of humpback whales congregate during migration (Fig. 1).

Further work in Shark Bay should include boat-based photo-identification studies for determining residence times and to provide an understanding of social interactions and behaviour of humpback whales, as well as monitoring environmental and man-made influences on the area.

## ACKNOWLEDGEMENTS

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